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# Magnetic Field Effects on NPDGamma Photodiodes

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Three types of photodiodes were tested in a perpendicular 10 G magnetic field: a 3", a cylindrical 5", and a bell-shaped 5". With an LED providing light, for signals of size up to $\sim$1 V from the 10 M$\Omega$-gain preamplifier, the photodiodes were affected respectively at levels of $+8 \times 10^{-4}$, $-1 \times 10^{-2}$, and $-1 \times 10^{-1}$. The 3" photodiode is clearly the least affected.

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The NPDGamma experiment requires its photodiode detectors to perform in a 10 G magnetic field. While this field will be constant, it is preferred to have the detectors not be susceptible to magnetic fields. For large effects, small fluctuations in the field could cause pulse-to-pulse variations in the asymmetry. If somehow coupled to the neutron spin, this could cause a false asymmetry in the experiment. Since NPDGamma needs to make a $10^{-4}$ asymmetry measurement per pulse, fluctuations of detector response of that size would be an unacceptable source of noise.

## Setup

A test setup was assembled, consisting of the following.

- A signal generator and simple LED circuit (green LED and 1 kΩ resistor), to produce pulsed light at 90 Hz.
- The photodiode, unshielded, inside a light-tight box.
- A small box containing the preamplifier circuit (see Ref. [1], 10 MΩ gain resistor) and two switched 45 V batteries, to provide bias voltage of 90 V for the photodiode. The preamplifier chip requires ±15 V.
- Helmholtz coils (radius 15", 143 turns, R = 3 Ω, 40 G field provided by 12 A [2]) which could accommodate the light-tight box, and a 10 V/3 A power supply.
- A lock-in amplifier (Stanford Research Systems model SR830) to measure the output signal from the preamplifier circuit.

A representation of the setup is shown in Fig. 1.

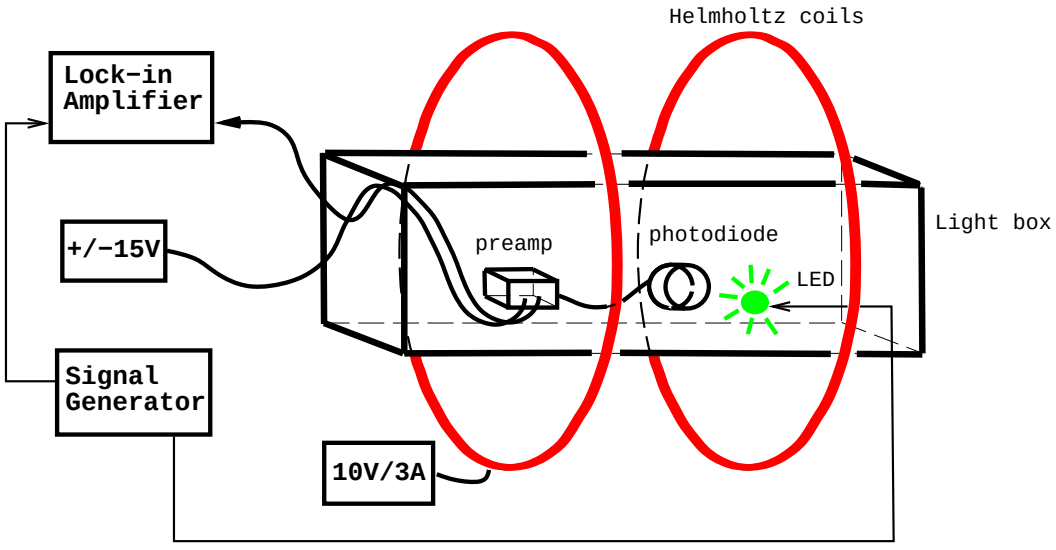


Figure 1: Depiction of test setup. The coils produced a 0-10 G field, and the photodiode could be oriented either parallel to or perpendicular to the field.

The photodiodes that were tested are listed in Table 1.

| | | | |
|---|---|---|---|
| 3" | ZC875 | R2046PT | '98.08 |
| 3" | ZC877 | R2046PT | '98.03 |
| 5" bell | ZC942 | R877PT | '98.06 |
| 5" cylinder | ZC958 | PT5 | '99.04 |

Table 1: Hamamatsu phototdiodes used in testing.

# Measurements

The signal generator was used to produce a 90 Hz signal for the LED. This pulsed light signal caused the photodiode to produce a current signal which was sent to the preamplifier circuit. The preamplifier converted the current signal into an output voltage. The signal generator allowed a DC offset on the voltage across the LED, which was adjusted to produce typically a 1 V offset on the signal out of the preamplifier.[1] Figure 2 shows the preamplifier output signal as it appeared on an oscilloscope.

The lock-in amplifier was used to measure the preamplifier output signal, indicated as the 'signal' in Fig. 2. The magnetic field was turned on and off, and the lock-in reading noted for each case ($S_{\rm on}$ and $S_{\rm off}$ respectively). The measurements were made

[1] The expected signal size for NPDGamma was estimated as follows.

- Peak number of neutrons (E<15 meV) per ms: $7 \times 10^7$.
- Gamma conversion efficiency: 65%.
- Photoelectrons per gamma: 500.
- Fraction of solid angle covered by each detector: 1/48.
- Charge per photoelectron: $1.6 \times 10^{-19}$.
- Milliseconds per second:1000.
- Gain resistor in preamplifier: 10 MΩ.

Mulitplying these factors together yields 0.75 V.

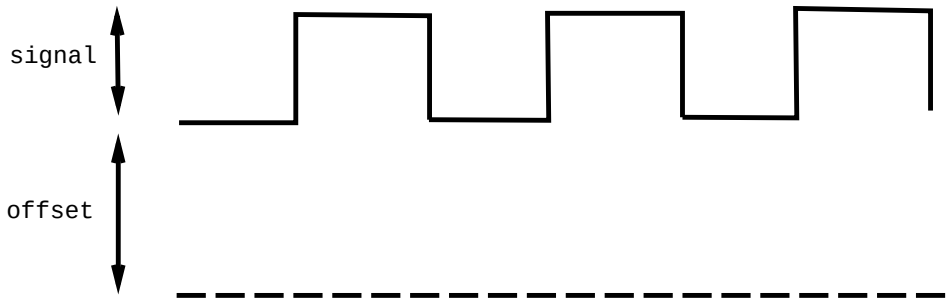


Figure 2: Output signal from preamplifier. The dashed line indicates 0 V. Typically the offset was 1 V, the signal 100 mV peak-to-peak. The signal frequency used for the measurements in this note was 90 Hz.

as soon as the reading was stable (typically after 30 s) to avoid drifting of the signal size. Each measurement was repeated, some many times, and all were highly reproducible. The raw differences between field on and field off are given in the Appendix to this note [3]. Results discussed here are the averages presented on the first page of the Appendix. The term 'effect' is used to mean the ratio $(S_{\rm on} - S_{\rm off})/S_{\rm off}$. A measured effect of $-0.01$ indicates that the photodiode's output is decreased by 1% for the given configuration and field strength.

Each photodiode type was tested in a perpendicular 10 G field and in a parallel 10 G field. Perpendicular and parallel directions were defined in relation to the axis of symmetry of the photodiode. In the perpendicular field the effect was measured for varying offsets ('offset' as defined in Fig. 2) and for varying field strengths. The field magnitude was measured using a Group3 Digital Teslameter. For these coils, the voltage in volts was equal to the field strength in gauss.

Results for the effect on the photodiodes for parallel and perpendicular 10 G fields are summarized in Table 2. The values, which are averages of many measurements, are reproducible to 10%.

| photodiode | field direction | effect |
|---|---|---|
| 3” | perpendicular | $+8 \times 10^{-4}$ |
| 3” | parallel | $+3 \times 10^{-4}$ |
| 5” cylinder | perpendicular | $-1 \times 10^{-2}$ |
| 5” cylinder | parallel | $-1 \times 10^{-4}$ |
| 5” bell | perpendicular | $-1 \times 10^{-1}$ |
| 5” bell | parallel | $-7 \times 10^{-3}$ |

Table 2: Summary of effect on photodiodes in 10 G magnetic field.

For each photodiode the perpendicular measurement includes measurements at offset values of 0.25 V, 0.50 V, 0.75 V, and 1.0 V. For the two 5” photodiodes the effect had no dependence on offset. For the 3” photodiode the change in offset caused the effect to vary by 10-20% ($7.3 \times 10^{-4}$ to $1.1 \times 10^{-3}$) but without any discernable trend. This variation is at the limit of the sensitivity of the measurements.

The 3” photodiode and the 5” photodiodes saw effects of different sign. The 3” signals were always increased by the presence of the magnetic field, regardless of geometry and orientation, including rotating the photodiode about its axis of symmetry. The 5” signals were always reduced by the fields. The 5” cylindrical photodiode was less affected by the parallel fields than was the 3” photodiode.

## Dependence on field strength

The effect of magnetic fields on the photodiodes is not linear with field strength. The effect was measured at several field strengths between 0 and 10 G, as shown in Fig. 3. The 5" photodiodes were unaffected for small fields, but for the larger field strengths the size of the effect changed rapidly. The 3" photodiode had most of its effect arise at the smaller field strengths, with the size of the effect largely independent of field strength from 6 to 10 G.

In each portion of Fig. 3, the total effect (difference between 0 G and 10 G) is equivalent to the results discussed previously. The top portion shows an effect of 4 mV for a signal of 40 mV, which is an effect of 0.1. The middle portion shows an effect of 0.3 mV for a signal of 30 mV, an effect of 0.01. The bottom portion shows an effect of 0.16 mV for a signal of 160 mV, an effect of 0.001. However, considering the portion of each curve from 6 G to 10 G, the 5" bell photodiode has an effect of (3 mV/40 mV)/4 G = 0.02/G. The 5" cylindrical photodiode has an effect of (0.3 mV/30 mV)/4 G = 0.003/G. With this method, the 3" photodiode has no measurable effect (less than (0.16 mV/160 mV)/10 G = 0.0001/G). These results are summarized in Table 3.

| photodiode | effect in field of ∼10 G |
|---|---|
| 3" | less than $+1 \times 10^{-4}$/G |
| 5" cylinder | $-3 \times 10^{-3}$/G |
| 5" bell | $-2 \times 10^{-2}$/G |

Table 3: Summary of effect of perpendicular magnetic field on photodiodes at field strength ∼10 G.

If the 10 G holding field were to have 1% fluctuations (0.1 G, an extremely con-

servative estimate), that would result in signal fluctuations of $2 \times 10^{-3}$ for the 5" bell photodiode, of $3 \times 10^{-4}$ for the 5" cylindrical photodiode, and of less than $1 \times 10^{-5}$ for the 3" photodiode. Since the NPDGamma experiment needs to make an asymmetry measurement of precision $1 \times 10^{-4}$ per pulse, the two 5" photodiode models are unacceptable. The 3" photodiode performs sufficiently well in a 10 G field to be used in the experiment.

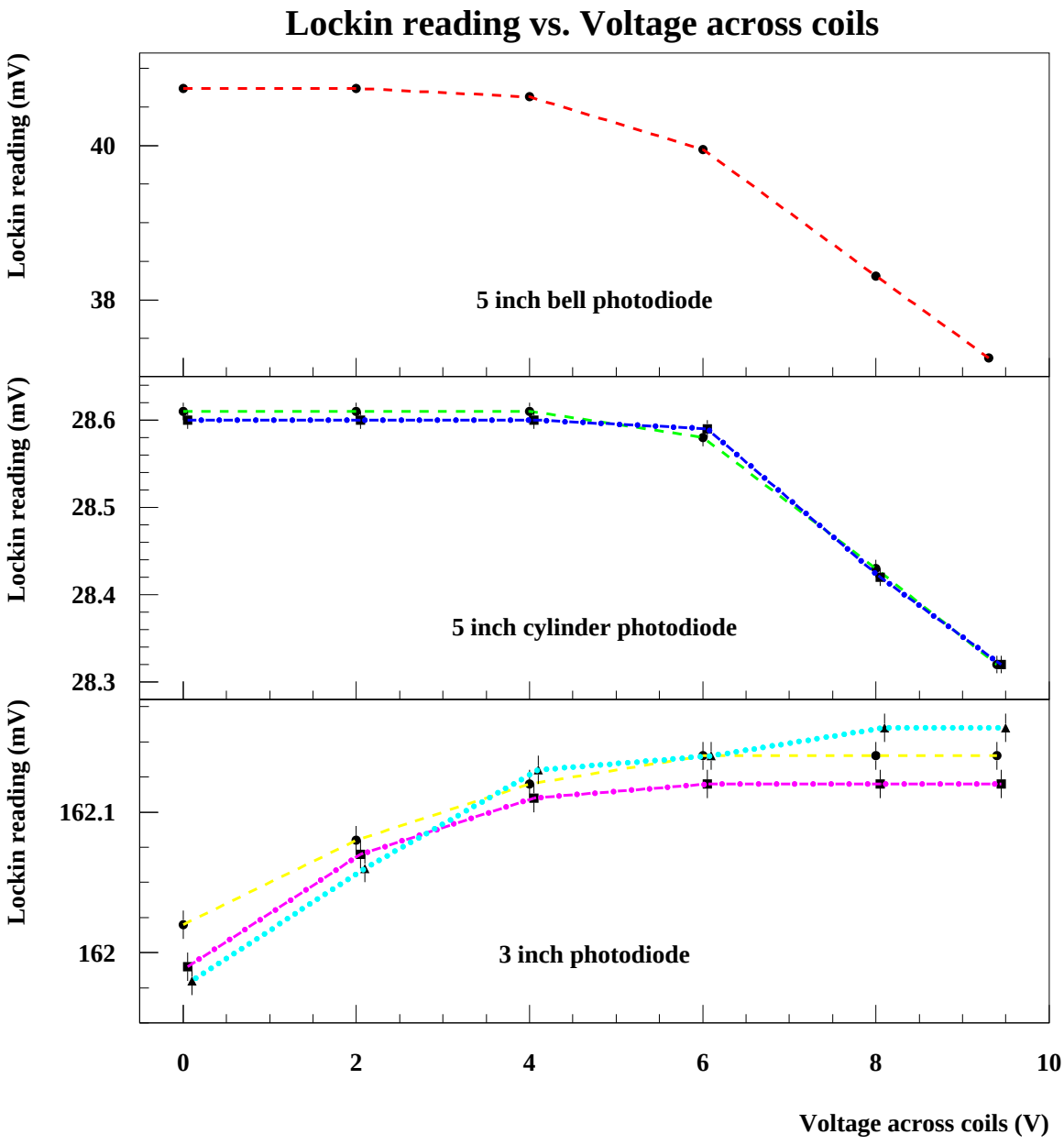


Figure 3: Effect on photodiodes vs. voltage across coils. For these coils, the voltage (V) is approximately equal to the magnetic field (G). The multiple curves on the two lower plots indicate repeated measurements.

# Summary

Three types of photodiodes were tested for their performance without any shielding in a magnetic field of ∼10 G. For the range of signal sizes that were tested, all exhibited an effect constant with signal size. For fields of ∼10 G, the effect on the 5" photodiodes varies significantly with field strength while the effect on the 3" photodiode is essentially constant (less than $+1 \times 10^{-4}$/G). For a perpendicular 10 G field, as compared to no field, the 3" photodiode signals were increased by approximately one part in a thousand ($+8 \times 10^{-4}$). The cylindrical 5" photodiode signals were decreased by one part in a hundred ($-1 \times 10^{-2}$), and the bell-shaped 5" photodiode signals were decreased by one part in ten ($-1 \times 10^{-1}$). The 3" photodiode is clearly the superior detector for use in a 10 G field.

# References

[1] NPDGamma proposal, p. 43.

[2] Numbers provided by Todd Smith.

[3] Photodiode logbook (1998-2000), pp. 120-136.

# Note Source

The source for this note is located on leneut.lanl.gov at:

`~gmitchell/tex/bfield_effect/`.

# Appendix: Raw Data

The results on this page are from the following seven pages of the appendix.
The differences given on the following pages are signal with field minus signal without.
"Effect" is defined as the difference divided by the signal without the 10 G field.

ZC958 is the cylindrical 5" photodiode.
ZC942 is the bell-shaped 5" photodiode.

Errors on these measurements are approximately 10%.

| photodiode | field direction | effect |
|---|---|---|
| 3" ZC875 | perpendicular | 0.0008 |
| 3" ZC877 | perpendicular | 0.0008 |
| 3" ZC877 | parallel | 0.0003 |
| | | |
| 5" ZC958 | perpendicular | -0.0110 |
| 5" ZC958 | perpendicular | -0.0097 |
| 5" ZC958 | parallel | -0.0001 |
| | | |
| 5" ZC942 | perpendicular | -0.0830 |
| 5" ZC942 | perpendicular | -0.1100 |
| 5" ZC942 | parallel | -0.0070 |

## 3" photodiode #1

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | | | | |
|---|---|---|---|---|---|
| logbook page | 122 | 123 | 123 | 124 | 125 |
| photodiode | 3" ZC875 | 3" ZC875 | 3" ZC875 | 3" ZC875 | 3" ZC875 |
| signal (mV) | 133.00 | 133.00 | 134.00 | 189.00 | 190.00 |
| offset (V) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| differences (mV) | 0.10 | 0.10 | 0.11 | 0.25 | 0.09 |
| | 0.07 | 0.04 | 0.12 | 0.19 | 0.18 |
| | 0.07 | 0.08 | 0.15 | 0.15 | 0.18 |
| | 0.06 | 0.06 | 0.10 | 0.18 | 0.09 |
| | 0.06 | | 0.14 | 0.12 | 0.12 |
| | 0.07 | | 0.15 | 0.21 | 0.12 |
| | 0.13 | | | 0.18 | 0.18 |
| | 0.04 | | | | 0.18 |
| | 0.10 | | | | 0.15 |
| | 0.07 | | | | 0.12 |
| | | | | | 0.12 |
| | | | | | 0.12 |
| | | | | | 0.15 |
| average difference | 0.08 | 0.07 | 0.13 | 0.18 | 0.14 |
| effect | 5.8E-04 | 5.3E-04 | 9.6E-04 | 9.7E-04 | 7.3E-04 |
| field direction | perp. | perp. | perp. | perp. | perp. |
| sign | + | + | - | - | + |

| | | |
|---|---|---|
| average effect for 3" ZC875: | perpendicular | 7.5E-04 |

## 3" photodiode #2

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | | | | | |
|---|---|---|---|---|---|---|
| logbook page | 135 | 135 | 135 | 135 | 135 | 135 |
| photodiode | 3" ZC877 | 3" ZC877 | 3" ZC877 | 3" ZC877 | 3" ZC877 | 3" ZC877 |
| signal (mV) | 46.00 | 39.50 | 161.20 | 146.40 | 124.00 | 101.00 |
| offset (V) | 1.00 | 0.75 | 1.00 | 0.75 | 0.50 | 0.25 |
| differences (mV) | 0.02 | 0.01 | 0.15 | 0.17 | 0.07 | 0.09 |
| | 0.03 | 0.03 | 0.14 | 0.16 | 0.10 | 0.11 |
| | 0.03 | 0.03 | 0.13 | 0.15 | 0.10 | 0.09 |
| average difference | 0.03 | 0.02 | 0.14 | 0.16 | 0.09 | 0.10 |
| effect | 5.8E-04 | 5.9E-04 | 8.7E-04 | 1.1E-03 | 7.3E-04 | 9.6E-04 |
| field direction | perp. | perp. | perp. | perp. | perp. | perp. |
| sign | - | - | - | - | - | - |

| | | |
|---|---|---|
| average effect for 3" ZC877: | perpendicular | 8.0E-04 |

## 3" photodiode #2

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | |
|---|---|---|
| logbook page | 134 | 134 |
| photodiode | 3" ZC877 | 3" ZC877 |
| signal (mV) | 160.50 | 160.40 |
| offset (V) | 0.70 | 0.05 |
| differences (mV) | 0.04 | 0.05 |
| | 0.09 | 0.04 |
| | 0.05 | 0.07 |
| | 0.06 | |
| | 0.07 | |
| | 0.03 | |
| average difference | 0.06 | 0.05 |
| effect | 3.5E-04 | 3.3E-04 |
| field direction | parallel | parallel |
| sign | + | - |

average effect for 3" ZC877: parallel 3.4E-04

## 5" cylindrical photodiode

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | | | |
|---|---|---|---|---|
| logbook page | 131 | 131 | 131 | 131 |
| photodiode | 5" ZC958 | 5" ZC958 | 5" ZC958 | 5" ZC958 |
| signal (mV) | 28.00 | 26.00 | 22.50 | 18.00 |
| offset (V) | 1.00 | 0.75 | 0.50 | 0.25 |
| differences (mV) | -0.28 | -0.28 | -0.26 | -0.18 |
| | -0.31 | -0.29 | -0.25 | -0.20 |
| | | -0.27 | | |
| average difference | -0.30 | -0.28 | -0.26 | -0.19 |
| effect | -1.1E-02 | -1.1E-02 | -1.1E-02 | -1.1E-02 |
| field direction | perp. | perp. | perp. | perp. |
| sign | - | - | - | - |

| | | |
|---|---|---|
| average effect for 5" ZC958: | perpendicular | -1.1E-02 |

## 5" cylindrical photodiode

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | | | |
|---|---|---|---|---|
| logbook page | 130 | 130 | 133 | 133 |
| photodiode | 5" ZC958 | 5" ZC958 | 5" ZC958 | 5" ZC958 |
| signal (mV) | 28.30 | 28.30 | 181.50 | 180.40 |
| offset (V) | 1.00 | 1.00 | 0.75 | 0.75 |
| differences (mV) | -0.30 | -0.27 | -0.01 | -0.03 |
| | -0.28 | -0.27 | 0.01 | -0.03 |
| | -0.28 | -0.26 | -0.02 | -0.04 |
| | -0.27 | -0.27 | 0.01 | -0.04 |
| | | | | -0.02 |
| | | | | -0.02 |
| average difference | -0.28 | -0.27 | 0.00 | -0.03 |
| effect | -1.0E-02 | -9.5E-03 | -1.4E-05 | -1.7E-04 |
| field direction | perp. | perp. | parallel | parallel |
| sign | + | - | - | + |

| | | |
|---|---|---|
| average effect for 5" ZC958: | perpendicular | -9.7E-03 |
| | parallel | -9.0E-05 |

## 5" bell photodiode

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | | | |
|---|---|---|---|---|
| logbook page | 128 | 128 | 128 | 128 |
| photodiode | 5" ZC942 | 5" ZC942 | 5" ZC942 | 5" ZC942 |
| signal (mV) | 41.50 | 37.00 | 32.00 | 24.00 |
| offset (V) | 1.00 | 0.75 | 0.50 | 0.25 |
| differences (mV) | -3.48 | -3.05 | -2.63 | -1.97 |
| | -3.47 | -3.06 | -2.59 | -2.06 |
| | | | | |
| average difference | -3.48 | -3.06 | -2.61 | -2.02 |
| effect | -8.4E-02 | -8.3E-02 | -8.2E-02 | -8.4E-02 |
| | | | | |
| field direction | perp. | perp. | perp. | perp. |
| sign | + | + | + | + |

| | | |
|---|---|---|
| average effect for 5" ZC942: | perpendicular | -8.3E-02 |

## 5" bell photodiode

10 G field
"signal" means lock-in reading
actual peak-to-peak square wave signal is 2.22*lock-in reading
"sign" of field is arbitrary but +/- are opposite for same photodiode

| | | | | |
|---|---|---|---|---|
| logbook page | 126 | 126 | 126 | 126 |
| photodiode | 5" ZC942 | 5" ZC942 | 5" ZC942 | 5" ZC942 |
| signal (mV) | 187.00 | 187.00 | 183.00 | 183.00 |
| offset (V) | 1.00 | 1.00 | 1.00 | 1.00 |
| differences (mV) | -1.16 | -1.37 | -12.51 | -26.97 |
| | -1.25 | -1.37 | -12.75 | -26.91 |
| | -1.22 | -1.43 | -13.12 | -25.63 |
| | -1.22 | -1.46 | -13.21 | -25.72 |
| | | -1.46 | -13.79 | |
| | | -1.40 | -13.73 | |
| average difference | -1.21 | -1.42 | -13.19 | -26.31 |
| effect | -6.5E-03 | -7.6E-03 | -7.2E-02 | -1.4E-01 |
| field direction | parallel | parallel | perp. | perp. |
| sign | + | - | - | + |

| | | |
|---|---|---|
| average effect for 5" ZC942: | perpendicular | -1.1E-01 |
| | parallel | -7.0E-03 |